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Headwater valley response to climate and land use changes during the Little Ice Age in the Massif Central (Yzeron basin, France)

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ABSTRACT

The geomorphological response of valley bottoms in eastern France to climatic fluctuations of the Little Ice Age (LIA) was investigated using sedimentological analysis together with optically stimulated luminescence (OSL) and radiocarbon dating. Diachronic mapping of land use since the beginning of the nineteenth century was also carried out. Since A.D. 1500, the valley bottoms experienced three cycles of aggradation and subsequent incision, each characterized by paired periods of high and low detritic activity. While the impact of human activity on the aggradation of the alluvial plain is observed, the vertical dynamics of the valley bottom deposits seemingly were also linked to the hydroclimatic fluctuations during the LIA. The sensitivity to these fluctuations was increased by human activity at the scale of the basin. Variations of the winter North Atlantic Oscillation (NAO) and solar activity from the last five centuries correlate with wet and cold phases during which valley bottoms accumulated, and dry and warm phases during which the streams incised into the valley floors. This fluvial sensitivity to the meteorological conditions induced temporal variations in sedimentary supply originating from either direct input from remnants of periglacial alluvial sheets or local rocky outcrops and/or from indirect input from the erosion of alluvial and colluvial deposits. These two components, combined with the sheet runoff over the ploughlands, express the complex coupling between hillslopes and valley bottoms in the headwater catchments. This caused a cascade-shaped transit of the sediments characterized by alternating phases of storage and removal.

1. Introduction

The Little Ice Age (LIA) is the last pronounced period of climate cooling, which was defined by historians and Earth Sciences as comprising *stricto sensu* A.D. 1550–1850 (Lamb, 1977; Grove, 1988; Acot, 2005). This episode is marked by a significant advance of Northern Hemisphere glaciers owing to long and severe winters and relatively cool and wet summers. These climatic conditions are particularly well documented by historical climatology studies through the evolution of the grape harvest dates (Dufour, 1870; Angot, 1883; Le Roy Ladurie, 1967; Chuine et al., 2004; Meier et al., 2007; Garnier et al., 2011; Daux, 2012) and the comparison of iconographic representations of glaciers (Le Roy Ladurie, 1967; Nussbaumer et al., 2012; Zumbühl and Nussbaumer, 2012). Some work has also been conducted on the geomorphological evolution of rivers and valley bottoms since the Medieval Climate Optimum (Bravard, 1989, 2000; Rumsby and Macklin, 1996; Gob, 2005; Gob et al., 2008; Jacob-Rousseau and Astrade, 2010, 2014; Macklin et al., 2012;; Notebaert et al., 2014; Lespez et al., 2015). For example, Bravard (1989, 2000) has shown that the braided pattern of most rivers of the French Alps appeared after the increase of sediment production during the LIA, but sometimes with a significant time delay. This trend was not found in the Mediterranean area and the Massif Central, in part because of fewer studies on geomorphological adjustments of watercourses during the LIA (Gob et al., 2008; Cubizolle, 2009). In this regard, Jacob (2003) concluded that southeastern Massif Central rivers experienced some phases of short hydrosedimentary fluctuations, i.e., aggradation of their alluvial floor during periods of high sediment supply followed by incision rather than a bed metamorphosis like the Alpine rivers. Moreover, the manifestation of the LIA does not appear to be homogenous across the Mediterranean region (Berger et al., 2010) because low temperatures were associated with drought in the eastern part as in the Iberian Peninsula (Carozza et al., 2014); such an

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evolution could have decreased sediment production. Finally, Macklin et al. (1994, 1995) reported a negative feedback in semiarid Mediterranean mountainous landscapes, where the wetter climate could have increased the vegetation cover and then decreased hillslope coarse material supply.

In the present work, we focus on the internal secular rhythmicity of the LIA. Notably, the LIA was not a period of continuously disturbed climatic conditions over three centuries, but characterized by quiet phases interrupting the general trend. Indeed, some authors have shown that this period was not characterized by disturbed climatic conditions but known as an alternance of crises and lulls. It has been pointed out first in the southern Alps (Douguedroit, 1979; Jorda, 1980; Neboit, 1983; Gautier, 1992; Pichard, 1995; Miramont and Guilbert, 1997) then in the Languedoc (Berger et al., 2010) and the southeastern Massif Central (Jacob, 2003; Gob, 2005; Gob et al., 2008; Astrade et al., 2011). The fluvial sensitivity to these fluctuations may depend on the size of the basin. The timing of adjustments can also vary because the downstream progradation of debris from headwater streams to lower valleys presumably requires a relatively long time (Bravard, 1989, 1993; Gob et al., 2008; Astrade et al., 2011; Jacob-Rousseau and Astrade, 2014). According to Gob et al. (2008), the three main sedimentation phases of rivers and deltas occurred exactly at the same time as the principal torrential crises that affected the western Mediterranean during the LIA (see discussion below). Conversely, these episodes are interspersed with two multidecennial phases of severe droughts during the second half of the seventeenth and early eighteenth centuries and during the early nineteenth century (Carozza et al., 2014). Nevertheless, Wilhelm et al. (2012) observed a time delay in flood frequencies during the last four centuries between the southern Alps and the Mediterranean coast of Spain and the Cévennes area. According to these authors, these differences could be explained by two northwestern Mediterranean atmospheric circulation paths affecting the area with a frequency of 50 to 150 years.

This article presents a case study from the Yzeron basin based on optically stimulated luminescence (OSL) and radiocarbon dating of valley bottom deposits in order to understand the relative influence of climate and human occupation during the LIA. The first aim of this paper is to describe the internal secular rhythmicity of the LIA and its geomorphic implications as observed in valley bottom deposits. In light of what has been stated above, the geographical situation (in the northeastern part of the Massif Central) and the size of the studied hydrosystems (headwater basins) should argue for an early and sensitive recording of the internal LIA hydroclimatic fluctuations.

In line with our previous work (Preusser et al., 2011), the second aim is to assess the relative influence of land use evolution in the sedimentary filling of valley bottoms. Our initial hypothesis was that the valley floor in which current incision occurs has been developed during widespread agricultural activity (mainly ploughlands) and that incision could have been triggered by a later decline in sediment supply from cultivated hillslopes. However, Preusser et al. (2011) also highlighted that such small basins show high sensitivity to climate and land use variations. In order to answer the question regarding the forcing factors of sediment dynamics (hillslope soil erosion, valley bottom deposition, remobilization of valley bottom sediments), we require (i) a diachronic mapping of land use since at least the nineteenth century in the four studied subcatchments and (ii) a chronostratigraphic model of these valley bottom deposits. On the latter point, a review of different dating methods has been provided by Lang et al. (1999) showing that radiocarbon dating and dendrochronology are problematic for such sediments, as these methods rely on the dating of reworked material (i.e., wood). As a consequence, such dating approaches may overestimate the true age of sediment accumulation (e.g., Lang and Hönscheidt, 1999; Huckleberry and Rittenour, 2014). Luminescence methods are now frequently used for the dating of colluvial and alluvial sediments, as recently reviewed by Fuchs and Lang (2009).

2. Study area

The Yzeron basin (147 km^2) is a right-side tributary of the Rhône River located near the city of Lyon (Fig. 1). From west to east, in the

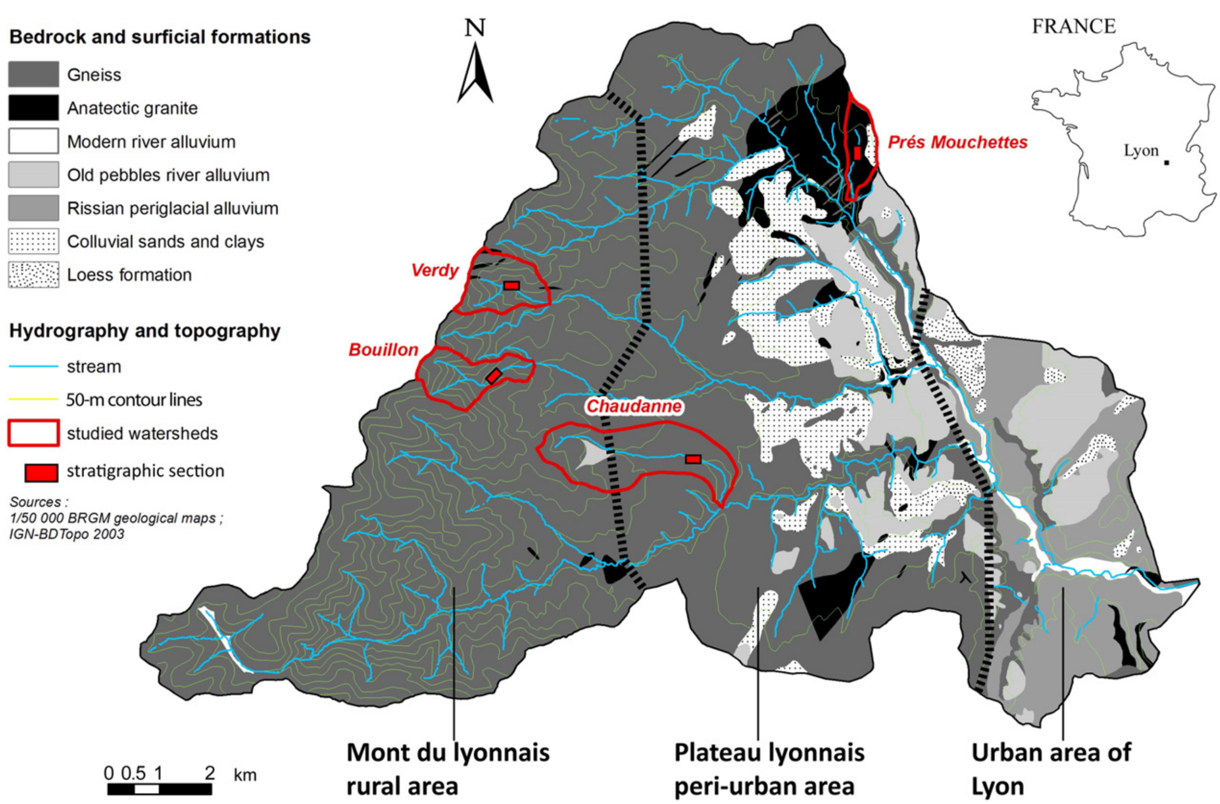

Fig. 1. Location of the four subcatchments studied inside the Yzeron watershed.